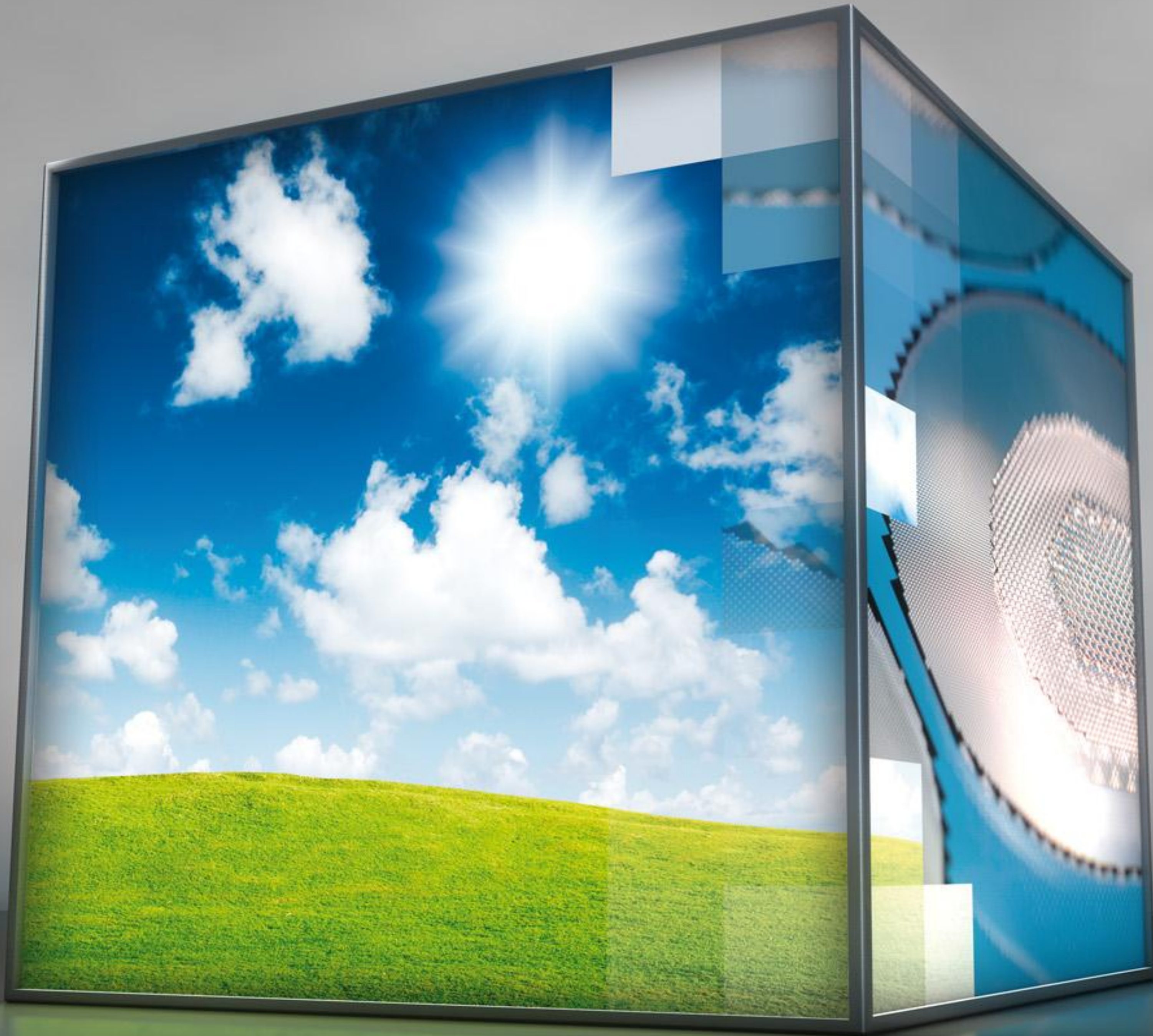
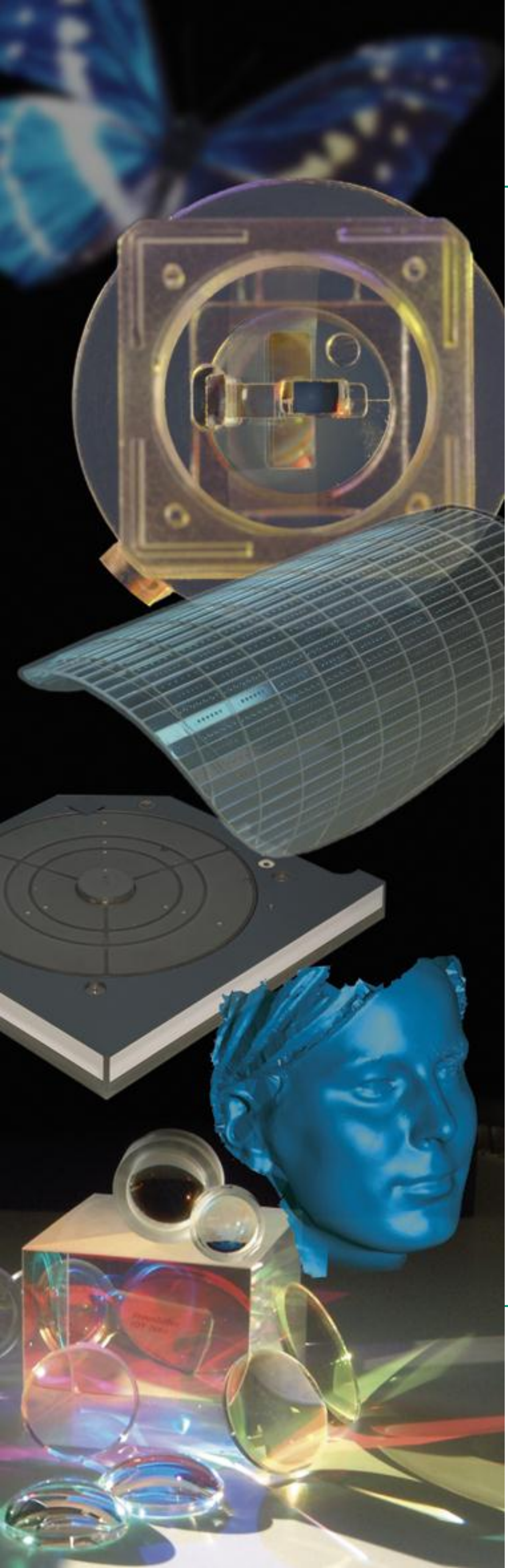


Solutions with light –
meet challenges and offer opportunities



New high reflective multilayer designs for the EUV and soft X-ray range

2012 International Workshop on
EUV and Soft X- Ray Sources

Marco Perske, Hagen Pauer, Tobias Fiedler, Sergiy Yulin,
Viatcheslav Nesterenko, Mark Schürmann, Torsten Feigl, Norbert Kaise

Fraunhofer IOF
Angewandte Optik und Feinmechanik Jena, Germany

Dublin, October 10th, 2012

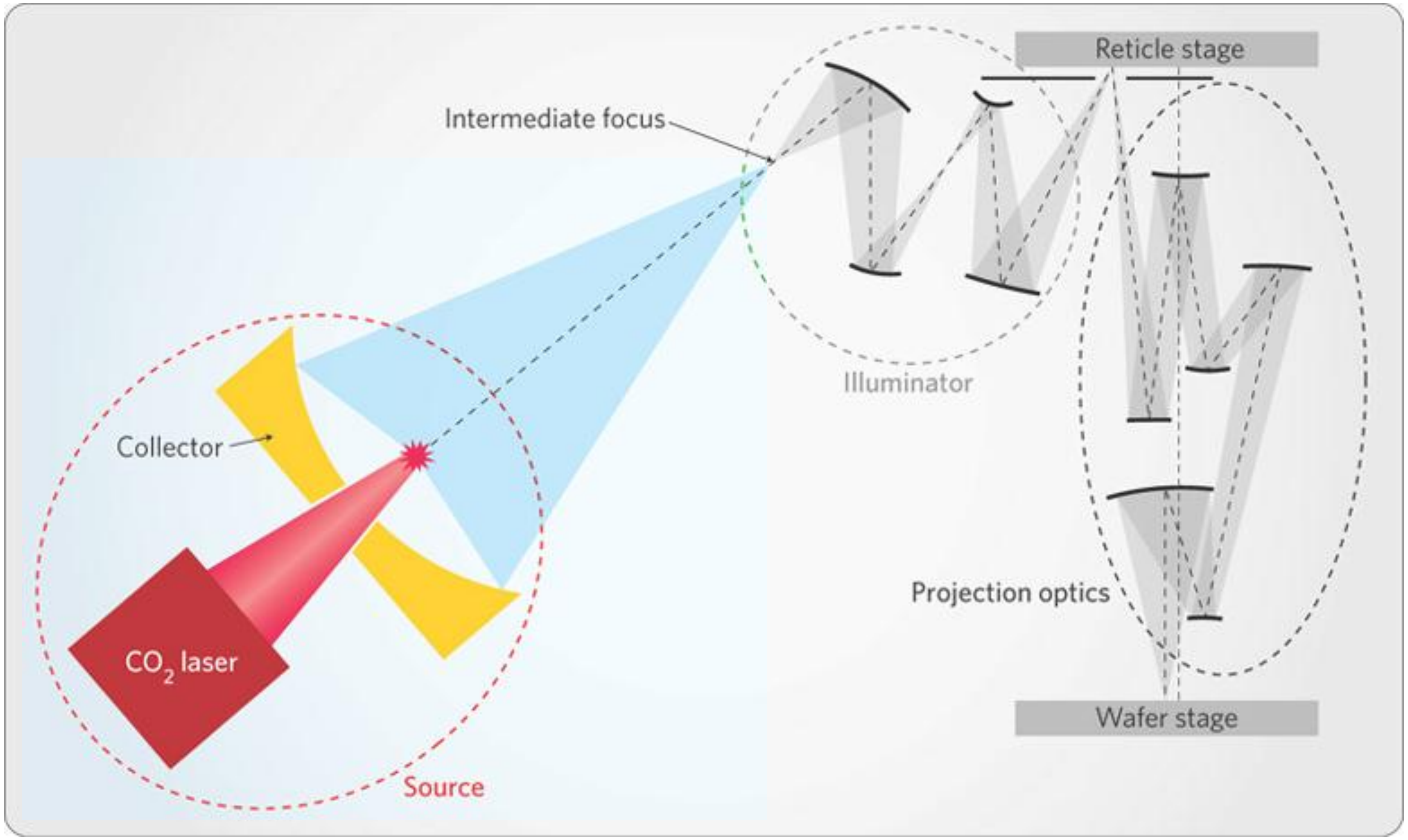
marco.perske@iof.fraunhofer.de

Fraunhofer IOF

Contents

- Introduction
- Update on EUV coating infrastructure @ Fraunhofer IOF
- Design and coating results
  - broadband / narrowband mirrors
  - broadband polarizers
  - beam splitter
- Summary and acknowledgement

Coating of LPP collector optics



[*Nature Photonics* **4**, 24-26 (2010)]

LPP collector coating challenges

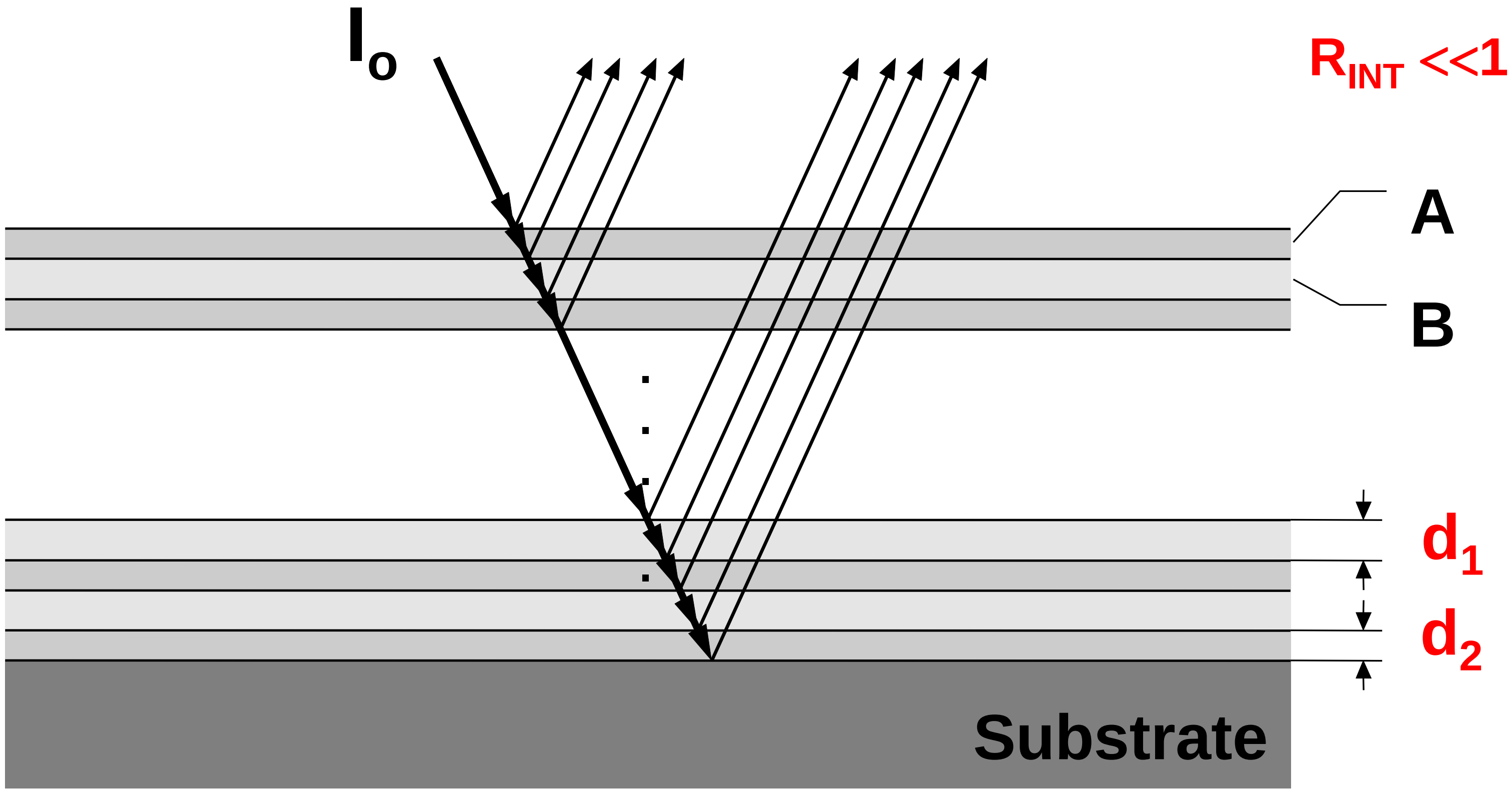
R > 65 %

λ = (13.5 ± 0.03) nm

→ Δd = 0.015 nm = 15 pm

- Diameter: > 660 mm
- Lens sag: > 150 mm
- Tilt: > 45 deg
- Weight: > 40 kg

Basics: Principle of constructive interference

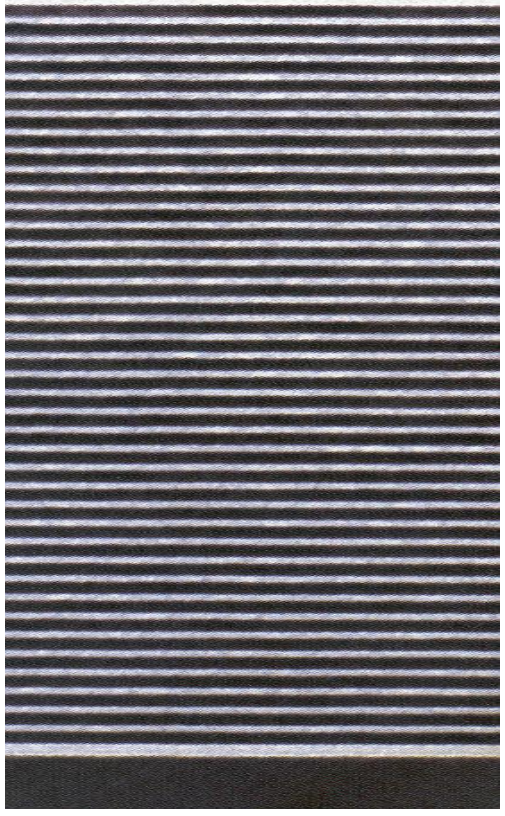


$d = 1$ -10 nm

$N = 20 – 500$

R_{INT} <<1 %

Mo/Si multilayer, TEM

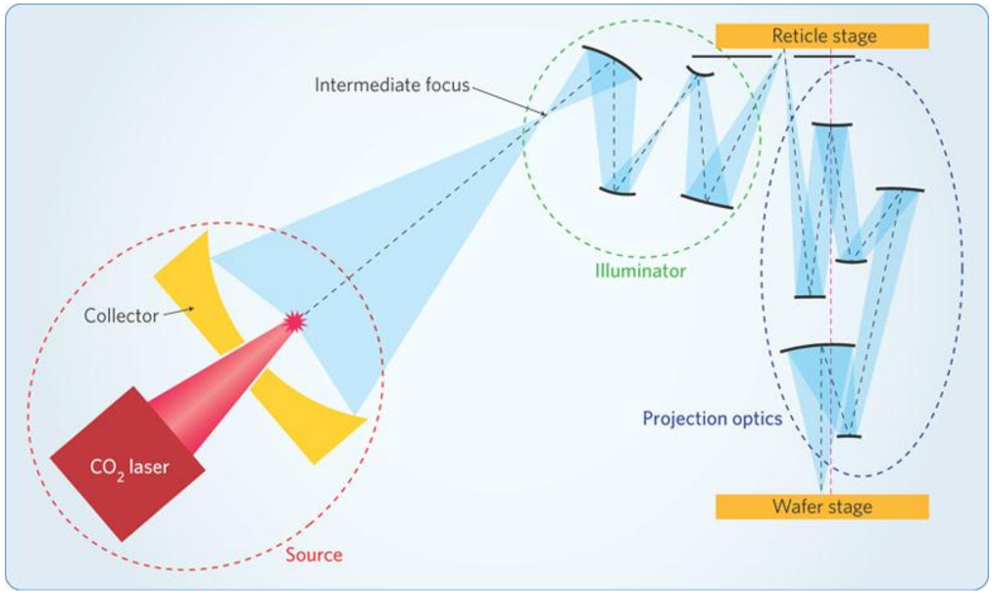


50 nm

E. Spiller, *Low-loss reflection coatings using absorbing materials*, Appl. Phys. Lett. 20, pp. 365-367, 1972.

EUV multilayer applications

[*Nature Photonics* **4**, 24-26 (2010)]



- Collector optics
- Illumination optics
- Projection optics
- Masks

- **Analysis, measurement and inspection tools**
  - **broad- /narrowband mirrors**
  - **broadband polarizers**
  - **beam splitter**

- optical modeling
- determination of optical constants
- ellipsometry
- monochromatic radiation
- etc.

Contents

NESSY – ‚New' EUV Sputtering System

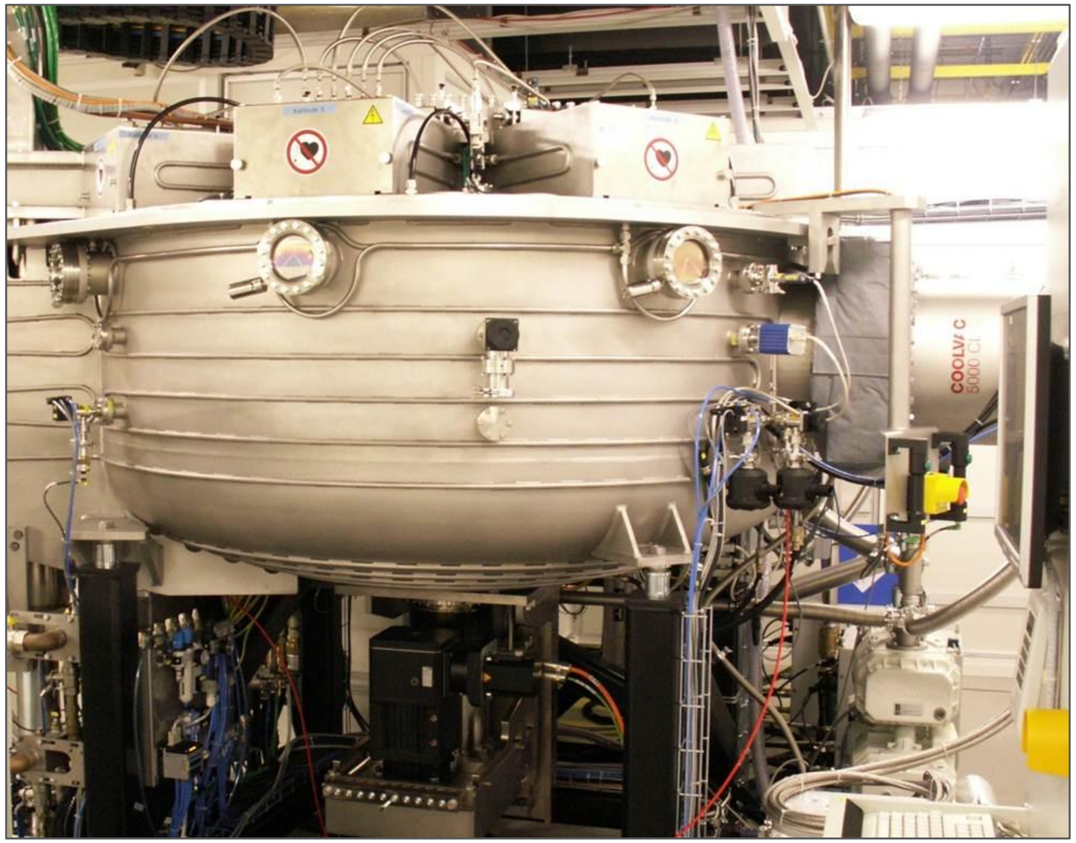
Design and realization of an EUV sputtering system

Conception:

- magnetron sputtering of rotating and fast spinning substrates **up to Ø 665 mm**
- four deposition targets
- deposition of graded multilayers on curved substrates

NESSY 2

- **Since 2010**
- **Optimized version of NESSY 1**
- **Load lock for substrates up to Ø 670 mm**
- **6 deposition targets**

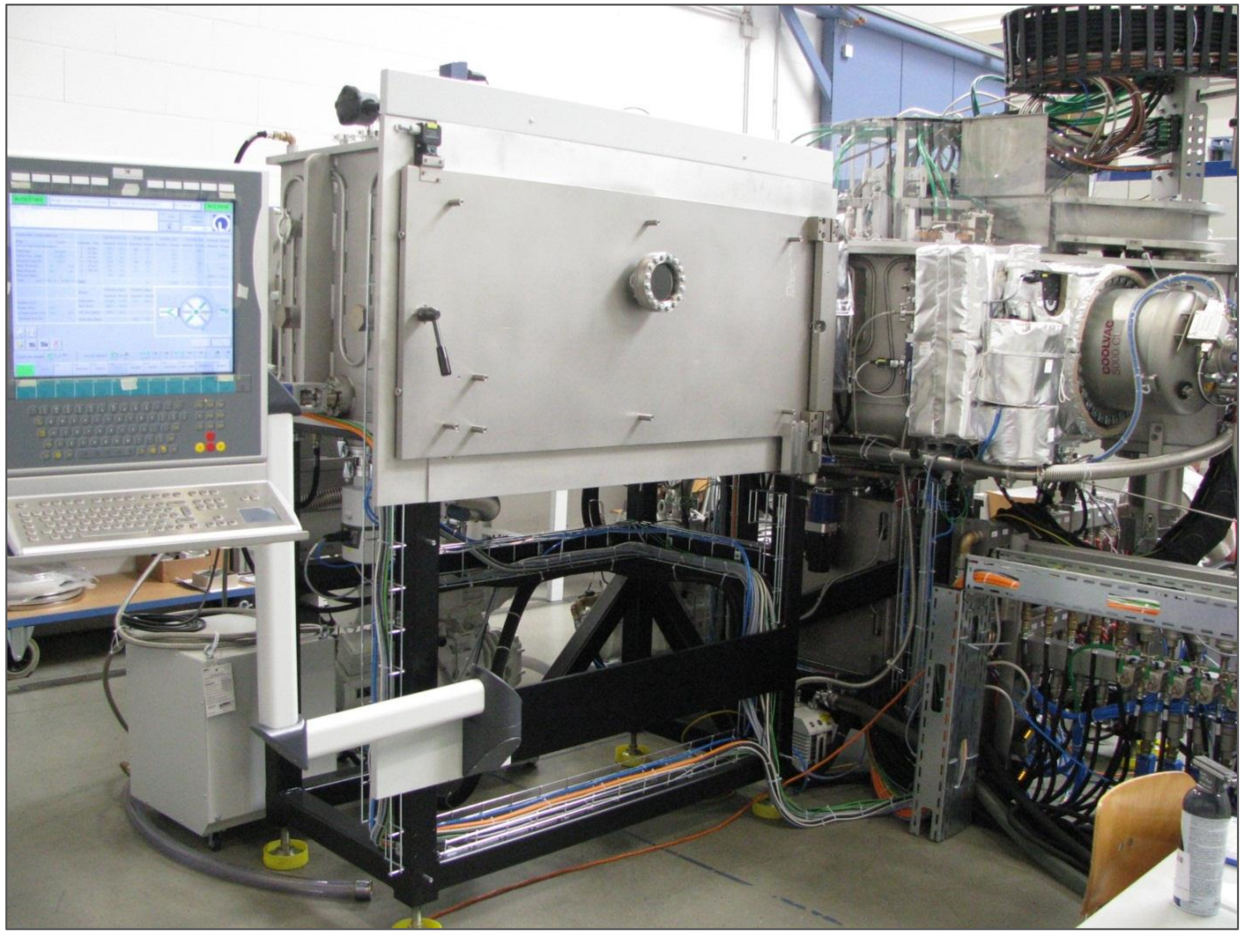


NESSY 3 - delivery to IOF: September 25, 2012

- **Substrate size up to Ø 200 mm**
- **6 deposition targets**
- **Application: R&D for EUVL and wavelength < 13.5 nm**

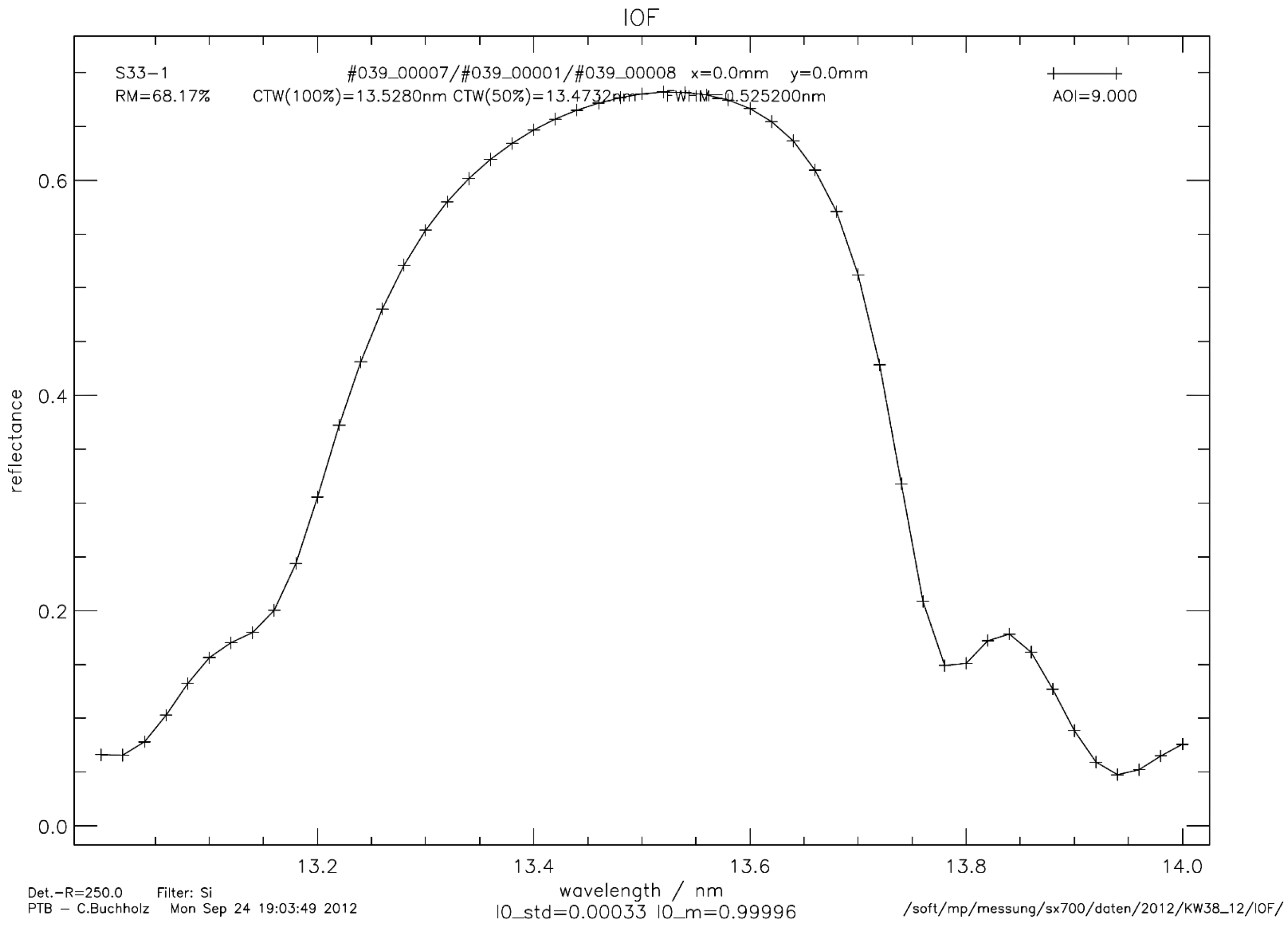
→ λ = 6.x nm

→ water window: λ = 2 nm - 5 nm



NESSY 3 – first EUV reflectance results

- Very first Mo/Si multilayer
- Reflectance: **R = 68.2 %**
- Peak: **λ = 13.53 nm**
- Center: **λ = 13.47 nm**
- FWHM: **0.525 nm**

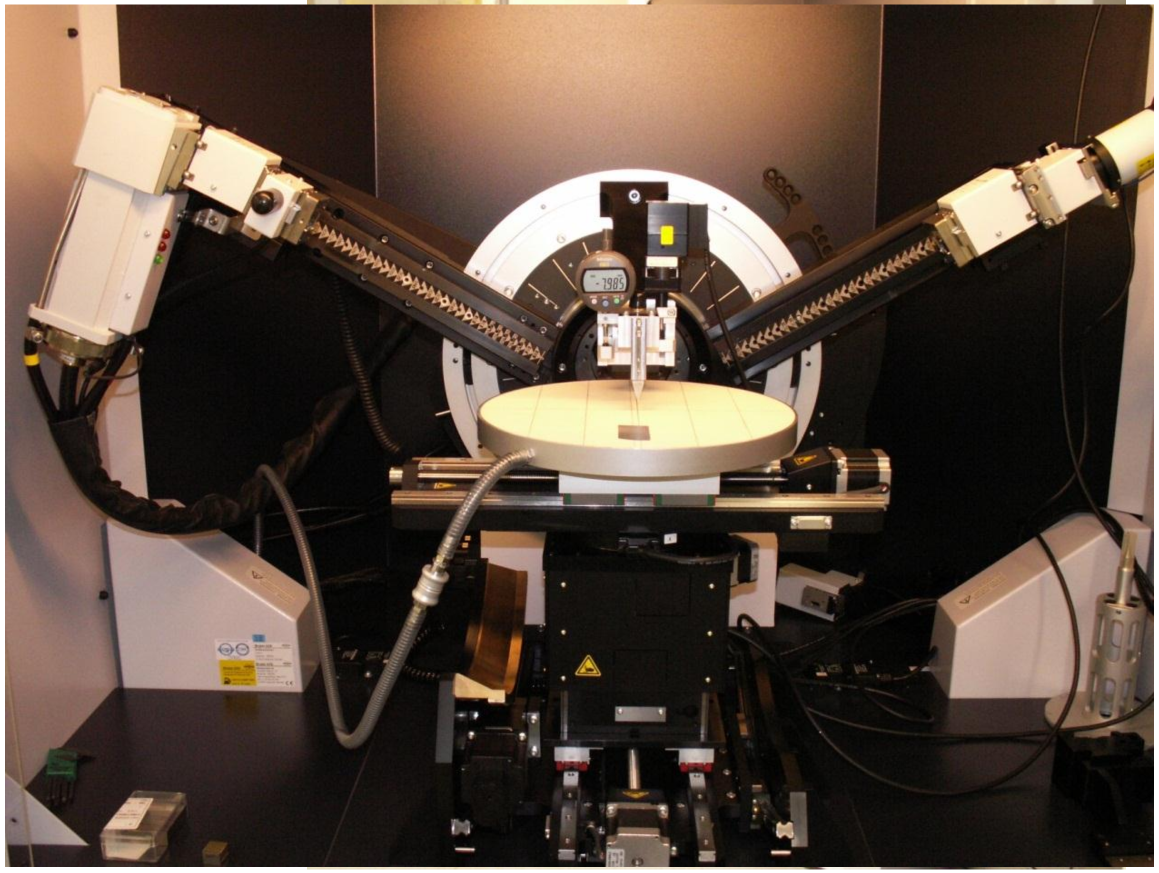


X-Ray Diffractometer D8 (Bruker AXS)

- Determination of layer thickness, roughness, density
- Determination of period thickness

  accuracy: Δd = ± 0.003 nm
- Automated measurement of ~ 50 samples

- **2nd D8 installed: August 2012**
- Optimized measurement speed
- Optimized sample adjustment
- ~ 30 % faster
- Analysis of crystalline structure



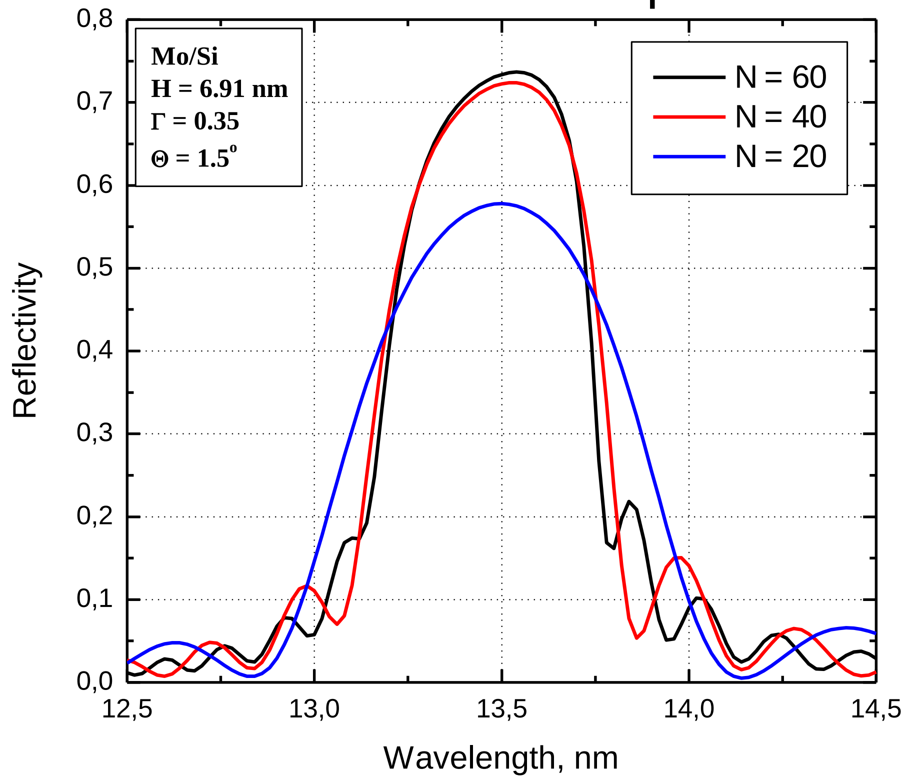
Contents

Design of broadband mirrors

3 provided opportunities

- change of optimal geometrical parameters (Γ and N)
- multistack design
- stochastic design

different number of periods N



N: 60 → 20:

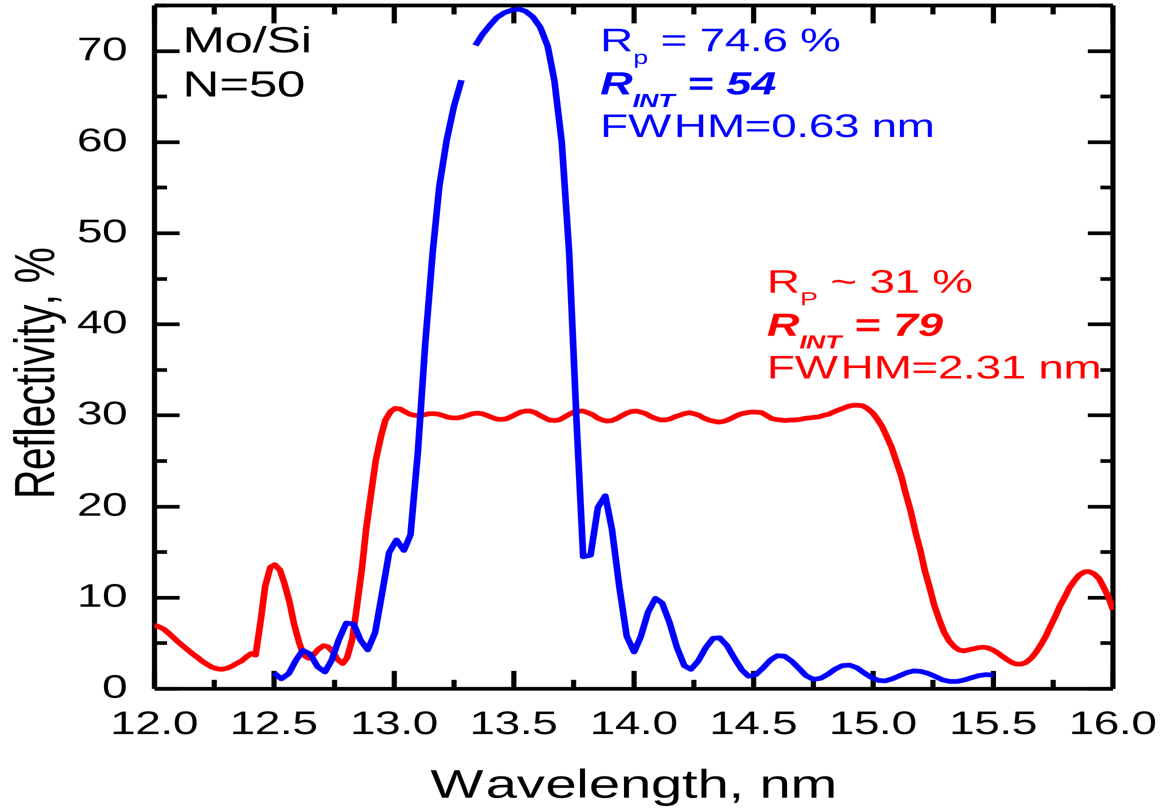
FWHM: 0.54 nm → 0.80 nm (+ 50%)

Design of broadband mirrors

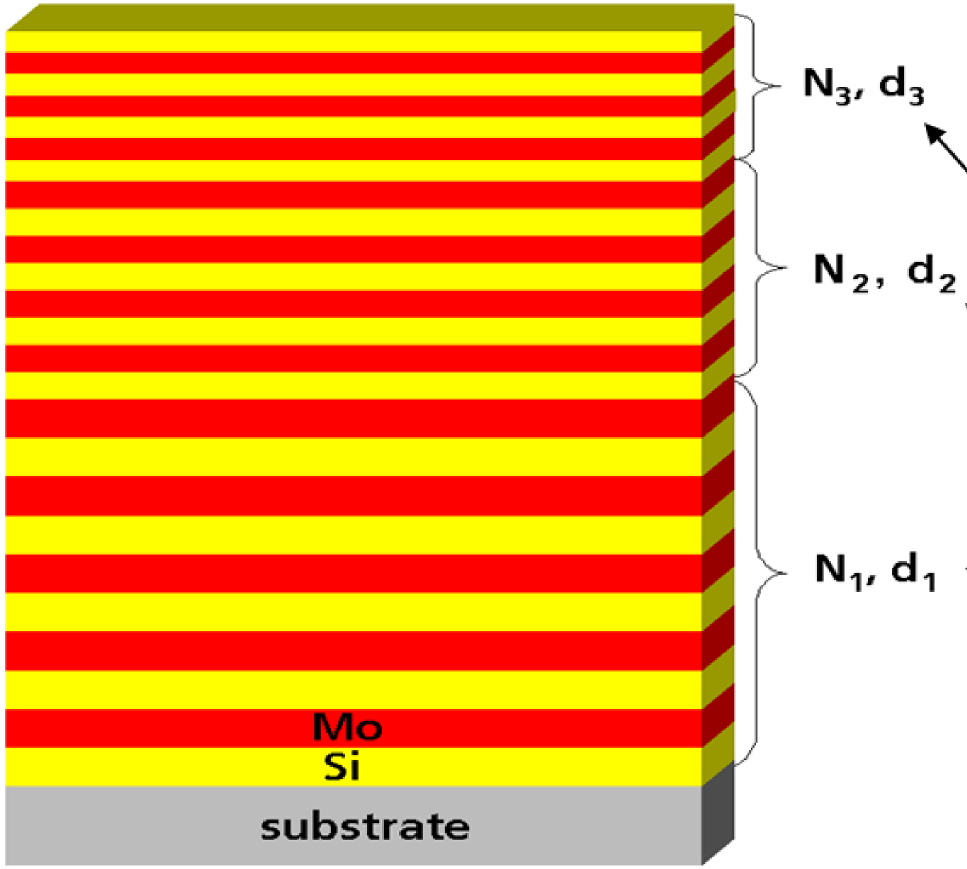
3 provided opportunities

- change of optimal geometrical parameters (Γ and N)
- multistack design
- stochastic design

stochastic design



Design of broadband mirrors (multistack design)



Target:

R > 40% @ λ = 13.5 nm

0° < Θ < 20°:

3 stacks:

N_3 = 5 d_3= 6.10 nm

N_2 = 15 d_2= 6.90 nm

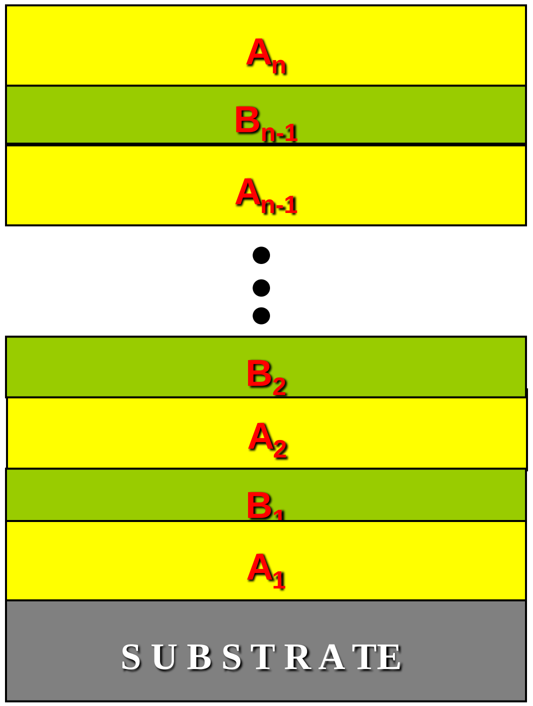
N_1 = 30 d_1= 7.22 nm

Design of broadband mirrors (stochastic design)

Thickness of ML material A and B

$A_1 \neq A_2 \neq \ldots \neq A_{n-1} \neq A_n$

$B_1 \neq B_2 \neq \ldots \neq B_{n-1} \neq B_n$



\+ **better optical performance**

but

- **very challenging**
- **process stability (up to 200 different layers)**
- **starting simulation parameters**
- **“complicated” design**
- **re-calculation nearly impossible**

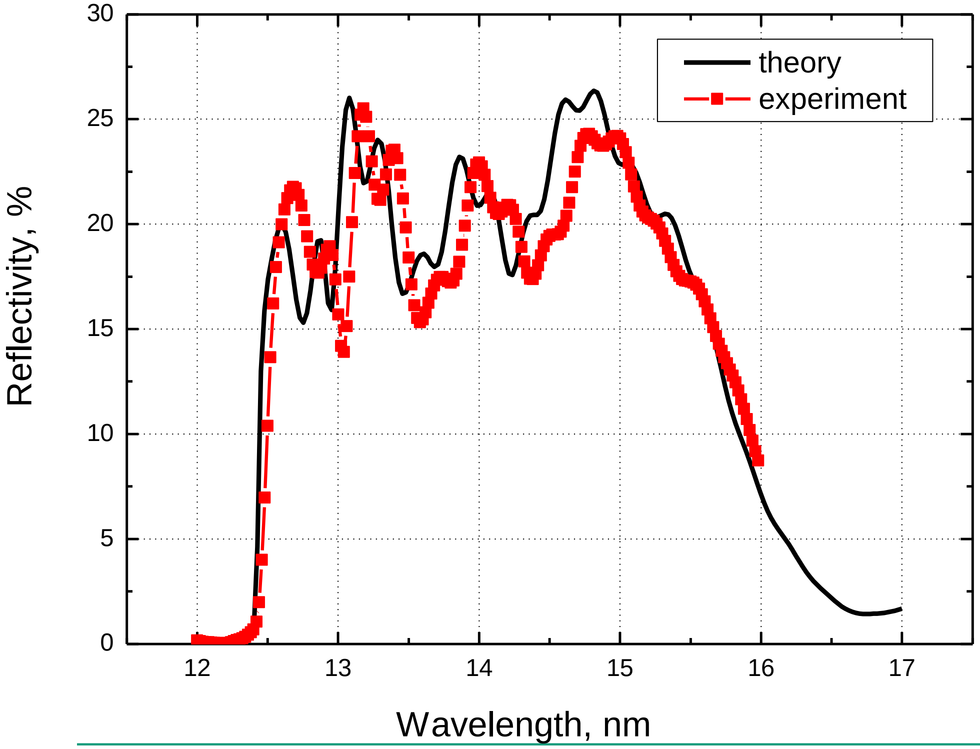
Experimental broadband multilayer results

3 stack design (60 layers)

AOI = 3 deg

λ = 12.5 nm – 15.0 nm)

R > 15 % (s-pol)

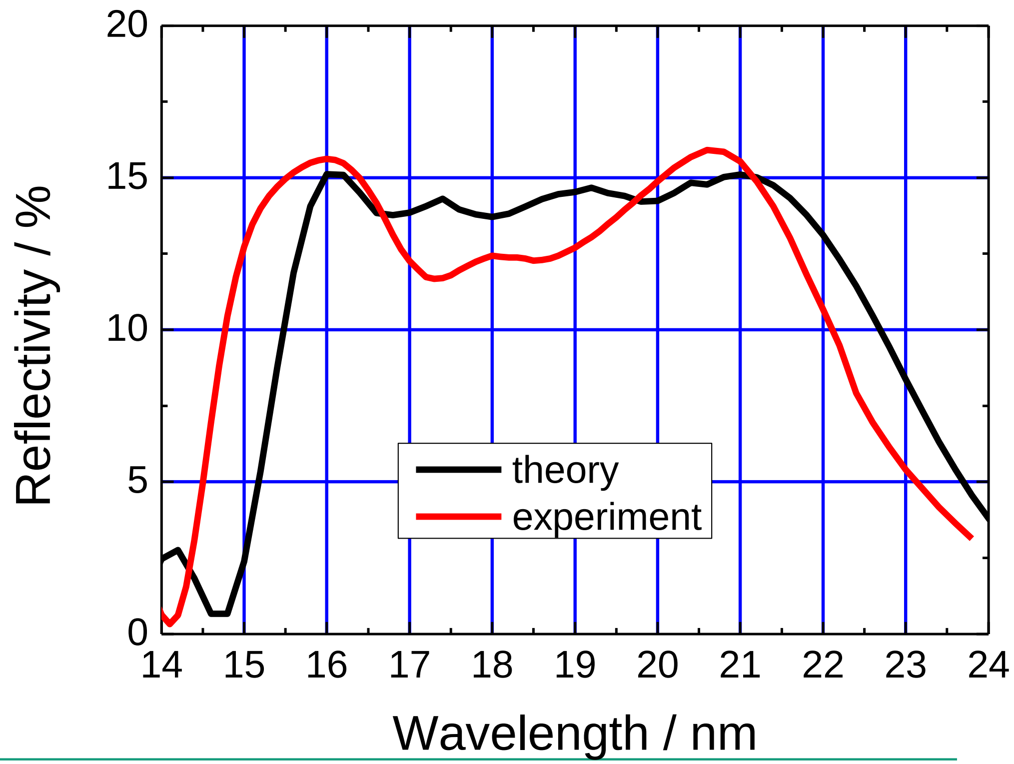


stochastic design (96 layers)

AOI = 3 deg

λ = 16.0 nm – 22.0 nm

R > 12 % (s-pol)

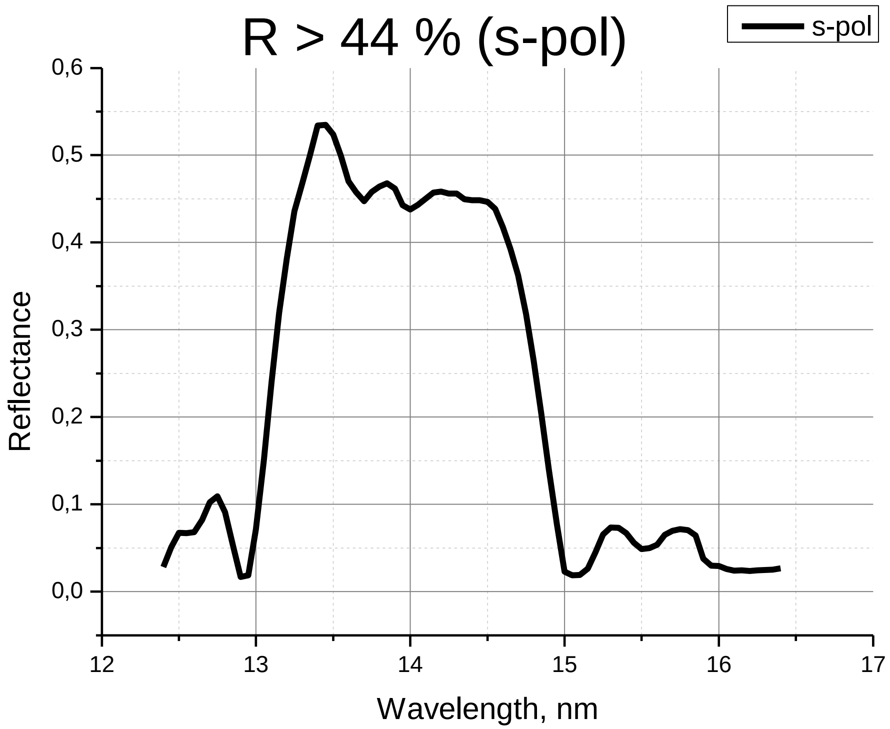


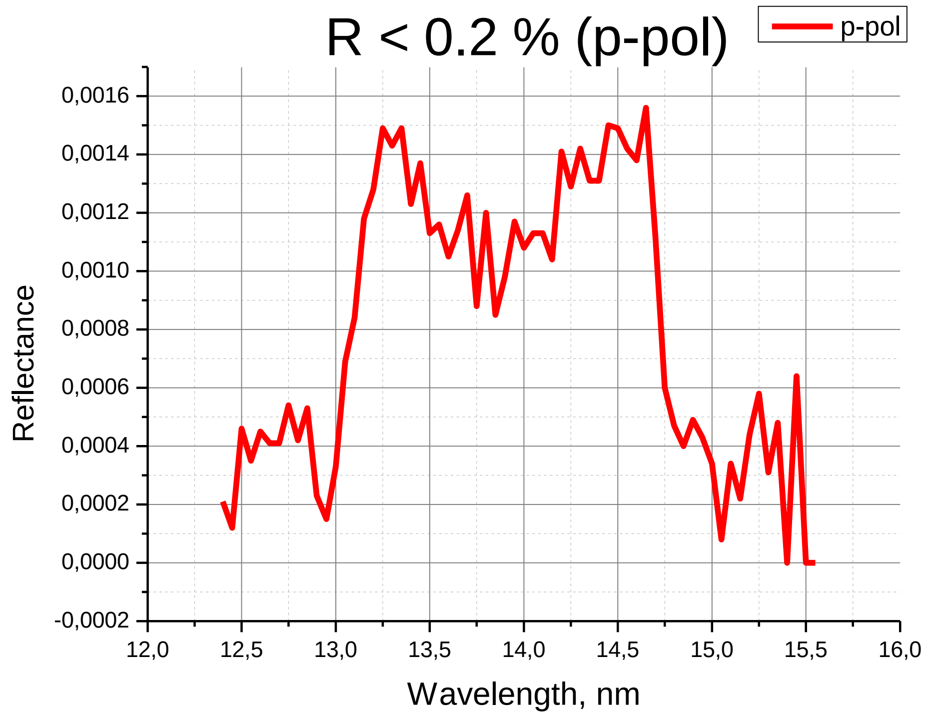
Experimental broadband polarizer results

Stochastic design (96 layers)

AOI = 42.5 deg

λ = 13.0 nm – 14.0 nm



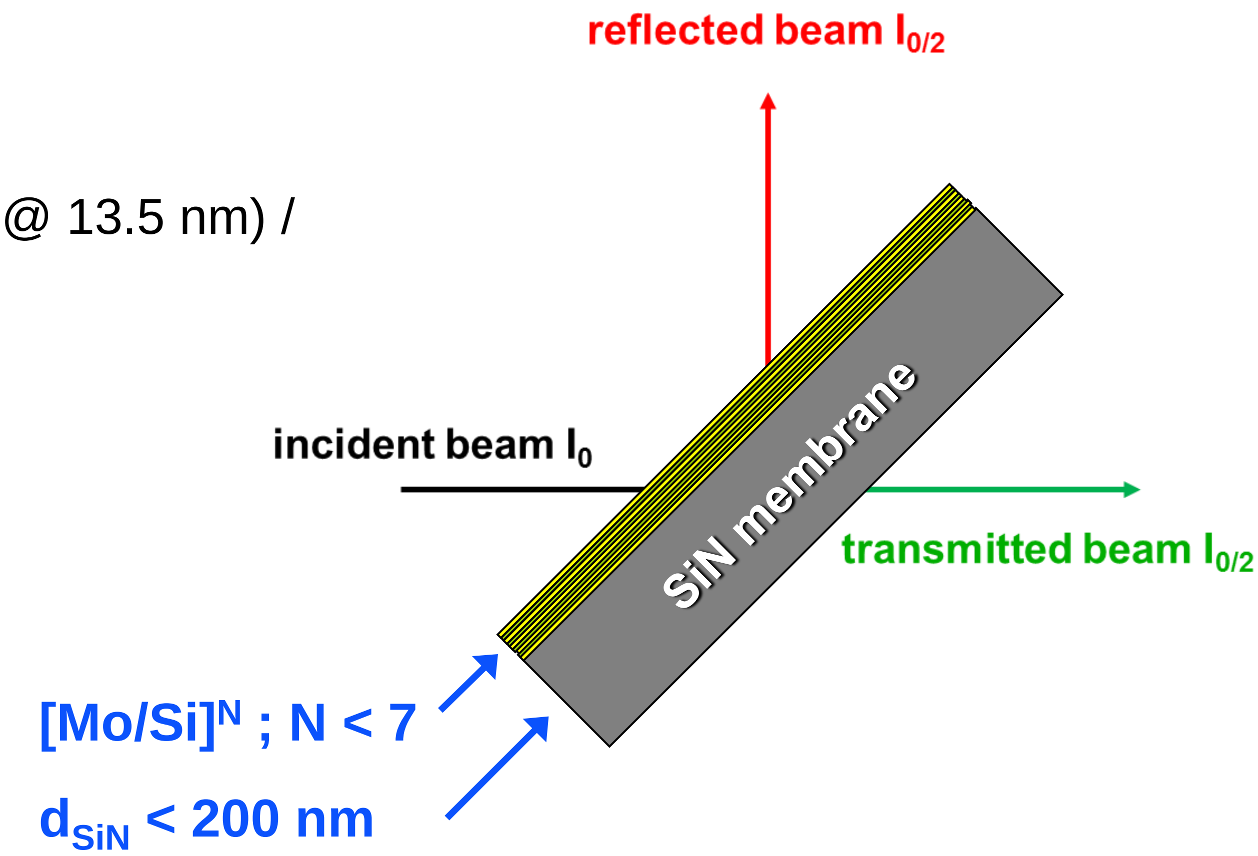


Beam splitter for λ = 13.5 nm

- AOI = 45 deg
- R = T
- Design:

  SiN membrane (low absorption @ 13.5 nm) /

  $[Mo/Si]^N$

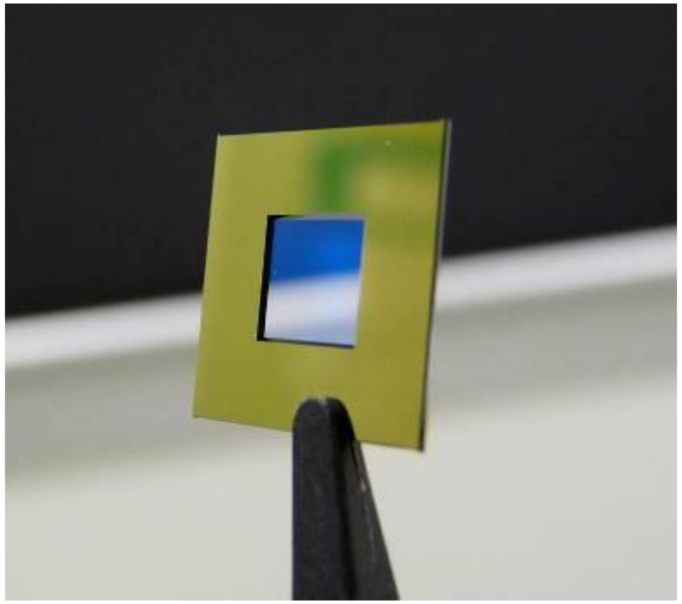


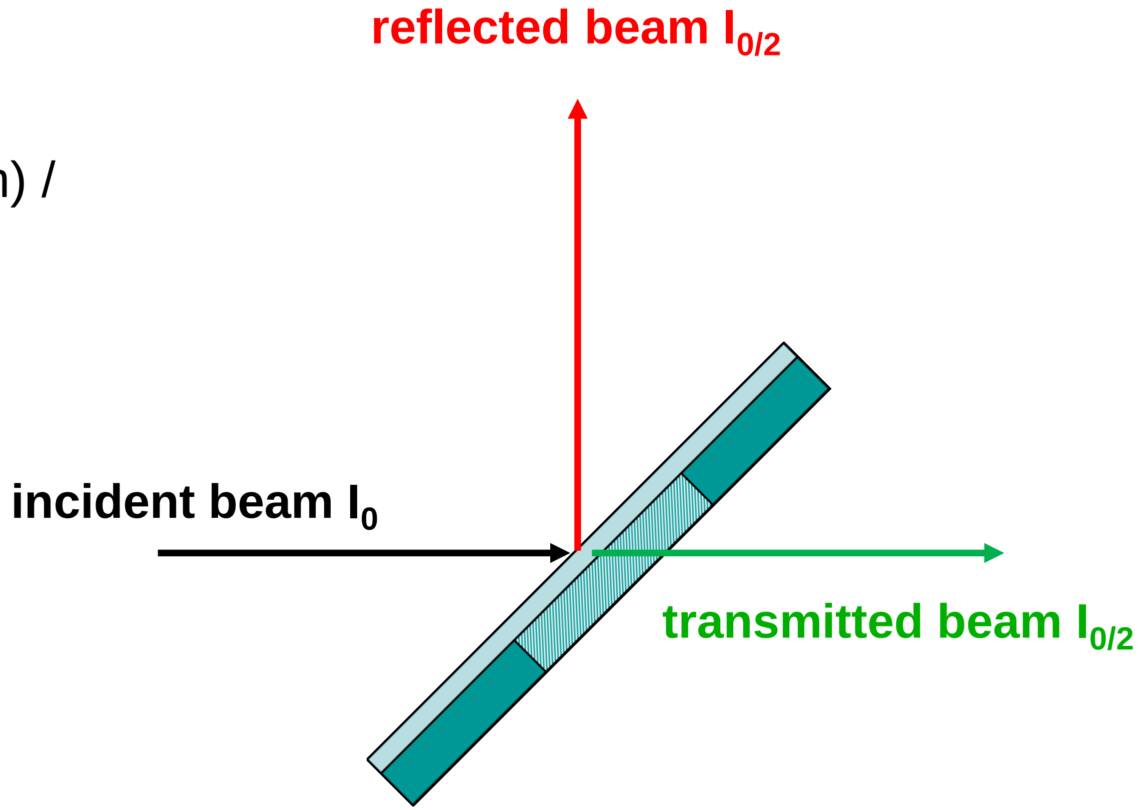
Beam splitter for λ = 13.5 nm

- AOI = 45 deg
- Design:

    SiN membrane (low absorption @ 13.5 nm) /

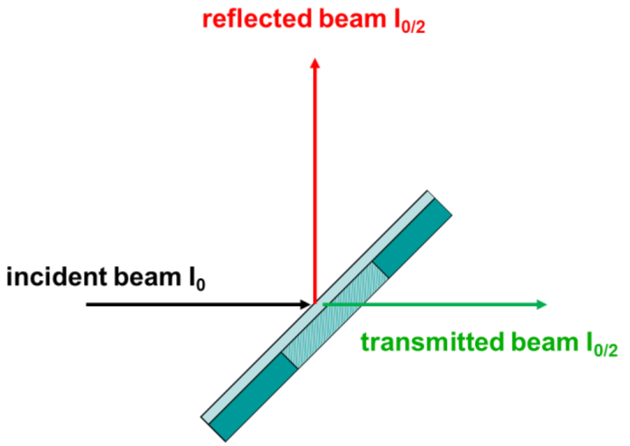
    $[Mo/Si]^N$

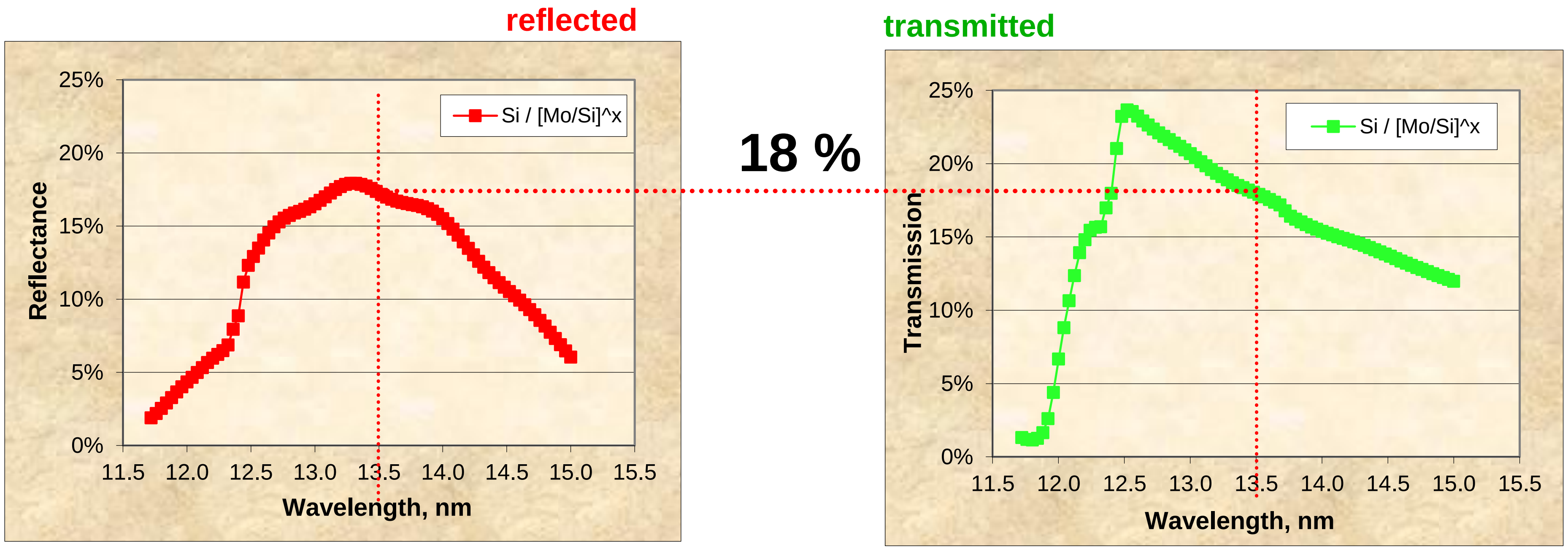




Experimental results

- AOI = 45 deg
- Design: SiN membrane / $[Mo/Si]^N$
- **R @13.5 nm = T @13.5 nm = 18 %**





Summary

- Custom-made calculation and realization of EUV multilayer optics
  - broad-/narrowband mirrors
  - broadband polarizers
  - beam splitter
- Main focus on optics for 13.5 nm
- Coating of optics for the broad XUV spectral range (λ = 1 nm – 100 nm)

Acknowledgements

- **PTB Berlin team for EUV reflectivity measurements:**
  Frank Scholze, Christian Laubis, Christian Buchholz, Annett Kampe
  Jana Puls, Christian Stadelhoff, Martin Biel
- **EUV project team @ Fraunhofer IOF**


Thank you!